SITUATIONAL AWARENESS, CREW RESOURCE MANAGEMENT AND OPERATIONAL PERFORMANCE IN FATIGUED TWO-MAN CREWS USING THREE STIMULANT COUNTERMEASURES

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ABSTRACT

The Warfighter lives a life of critical judgments, decisions, and risk taking. There is barely enough time to perform mission-essential tasks, let alone time to rest and rejuvenate body and mind. Army researchers have done a thorough job in the pursuit of countermeasures to Soldier fatigue that do not interfere with soldier performance, when that issue is couched in terms of individual soldiers performing fairly simple, repetitive tasks. Acceptable sedatives and stimulant preparations have been identified and their operational parameters described. However, it is not known how these agents perform when the dynamics of group/team interaction are injected into the research program. The DUO-WOMBAT-CS is the primary measure examined herein, and was chosen due to its focus on crew resource management and situational awareness in a complex task environment. Army aviators were subjected to over 64 hours of sleep deprivation, and were randomly assigned to one of four stimulant conditions (dextroamphetamine, modafinil, caffeine or placebo). The participants were repeatedly tested in pairs throughout the deprivation period. Testing included the WOMBAT, flights in the USAARL UH-60 research simulator, and various other tasks. Scores were compared over time and between drug groups, for the WOMBAT and the simulator performance. The analysis suggests that performance on the crew management and situational awareness-sensitive tasks done by crew-pairs is well attenuated over periods of fatigue by these stimulants. Simulator performance did not prove as sensitive to fatigue or drug condition as expected. Future work will attempt to redress this information shortfall, and to further explore the effects of these preparations on higher-order, crew-based soldier activities.

1. INTRODUCTION

Fatigue resulting from sustained combat operations takes a tremendous toll on service members, dangerously reducing physical and cognitive resources by as much as 25% per day of sleep deprivation (Belenky, et.al, 1994). The hazards of fatigue are especially crucial when interface with complex systems is involved. The Department of the Army TACTICS Field Manual (FM 3-90) directs tactical officers to approach their mission from the point of view of the individual soldier and his or her basic needs. Judicious use of sleep management, by which the soldier is ensured the maximum possible quantity and quality of sleep, has long been recognized as the most desirable fatigue countermeasure. However, modern training and combat demands may require a faster, simpler and easier strategy to short-circuit the ravages of fatigue. When mission parameters necessitate sleep loss and demand optimal alertness, pharmacological solutions may be the only viable remedy for fatigue-related deficits in performance and cognition.

The ability of stimulants to sustain soldier performance over extended periods of wakefulness has been well studied under single subject conditions, using simple, carefully structured tasks (e.g. Caldwell, et al., 2000, Wesensten et al, 2002). However, no studies have yet explored the stimulant/fatigue relationship in terms of its effect on higher-order cognitive operations, nor in an interactive group environment. This issue is critical, as most military duties require a minimum crew of two soldiers to perform to standard. Also, the changing Force requires more complex and sophisticated cognitive behavior from the soldier. Warfighter judgment, decision making and crew coordination are all key to mission success. It is not known if, and to what extent, stimulants as fatigue countermeasures will be upheld when the dynamic of group interaction is introduced. Similarly, it is not yet clear if stimulants as fatigue countermeasures will yield the traditional expected effects on higher order cognitive performance.

Caffeine is a non-regulated, widely used and accepted anti-fatigue preparation. Although it has few major side effects, as a very commonly used stimulant, caffeine can generate a tolerance in many users which diminishes its effects considerably. When administered in adequate doses to nontolerant participants, caffeine has long been known to mitigate fatigue in the laboratory (c.f. Penetar et. al, 1993). The effects profile for dextroamphetamine is just as well known, and has been established in both laboratory and field environments (Caldwell et al, 1994; Caldwell et al, 1995). However, dextroamphetamine is a Schedule II controlled substance with known abuse potential, which raises concern for the safety of our service members, particularly under the remote conditions and other stresses of combat. Modafinil appears to possess fatigue mitigation ability

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similar to that of dextroamphetamine, and it is a less-restricted Schedule IV drug with lower apparent abuse potential. The beneficial effects of modafinil in an aviation environment may be offset, to some extent, by the drug's purported side effect profile, which includes some reports of mild to moderate gastrointestinal and vestibular side effects (nausea, dizziness, etc.; Caldwell et al, 2000). A major objective of this research was to determine whether these stimulants, which traditionally counteract fatigue on simple tasks performed by individuals, could just as effectively sustain crew resource management and situational awareness in two-man crews.

2. METHOD

2.1. Subjects and Testing/Dosing Schedule

The study was approved by the local USAARL Human Use Committee and the MRMC Human Subject Research Review Board. Thirty-two rated and current UH-60 Army aviators were tested in pairs over a period of seven days. All volunteers were fully briefed as to study content before the researchers obtain informed consent; all participants were compensated for their time for this study.

After an acclimation period, the participants were kept awake for a period of 87 hours, and tested at fixed intervals throughout the day and night. Each pair of participants was randomly assigned one of four drug preparations: dextroamphetamine, modafinil, caffeine, or placebo (for a total of eight subjects per drug condition). The drugs were administered three times on each deprivation day (0000, 0400 and 0800) in order to keep an effective level of medication in the system. Dosages (per administration) were: dextroamphetamine: 5 mg, modafinil: 100mg, caffeine 200mg. (Total study dosage: dextroamphetamine: 30mg, modafinil: 600mg, caffeine: 1200 mg.) Participants in the placebo group received lactose filled capsules which were identical to those containing the active compounds.

The study was conducted in a double-blind fashion; that is to say, neither the researchers, nor the participants were aware of drug group assignment until the conclusion of the entire study. Performance on the DUO-WOMBAT-CS was recorded at each of three testing sessions per 24 hour period, (at roughly 0240, 1040 and 1840). Further, during each testing period, the two-man crew flew a one-hour profile in the USAARL UH60 flight simulator. These testing rotations yielded six sets of Wombat and flight data per pair over the deprivation period.

2.2. DUO-WOMBAT-CS

In order to access higher-order cognitive skills, as well as to introduce the two-man crew element, the DUO-WOMBAT-CS (henceforth 'WOMBAT') was adopted as central study measure. The WOMBAT is primarily intended as a measure of crew resource management in carrying out complex tasks, and is composed of several subtasks. The subtasks analyzed here were those which are performed by both members of a participant pair in tandem: tracking, 3D figure rotation, digit cancellation and quadrant location. Each of these WOMBAT subtasks incorporates both a standard cognitive test and a situational awareness/decision making component. For example, the tracking task consists of two basic psychomotor tracking tasks, one for each hand.

Further, onscreen information is present to help predict where the tracked objects will move next. Therefore, even at the individual level, higher order decision making elements such as prioritization, learned lessons, prediction and resource management are all integral to each subtask. In 'duo mode' the task introduces additional requirements of situational awareness, cooperative team performance, and group judgment and decision making. When set at 'duo mode,' only one member of the pair of participants may perform the basic task. The pair must come to a consensus as to which crew member will perform a given task. The pair must interact verbally and make decisions as to which participant is most likely to a) solve the problem with greatest accuracy and speed and b) garner the most points for a solution. Several screen indicators supply supportive information on each individual's performance, such as recent effectiveness, the value of each task, and current total points.

2.3. Flight Performance: USAARL UH-60 Flight Simulator. Flight performance was assessed using the USAARL UH-60 research flight simulator. This system is capable of monitoring any aspect of simulator control, from heading, air speed, and altitude, to global positioning system (GPS) readouts, switch positions, and operator console inputs. Flight performance scores, including root mean square (RMS) errors, were derived using specialized software routines developed in the Laboratory (Jones and Higdon, 1991). Flight profiles involved 7 standardized maneuvers for each pair of participants.

The extent to which each pilot performed the correct landing sequence, within established standards was evaluated by the simulator operator, along with the extent to which the pilots correctly performed the standard maneuvers listed above. The simulator data acquisition system calculates scores for a variety of

measures within each of the flight maneuvers to express how well participants maintained specific headings, altitudes, airspeeds, and other parameters. The duration of each flight was approximately 60 minutes. During each flight, one aviator served as pilot for half the flight (approximately 30 minutes) while the other aviator served as co-pilot. At the approximate half-way mark, the pilots switched positions and roles for the remainder of the flight. A USAARL research aviator supervised all aspects of the flight and ensured the correct timing and sequencing of each maneuver.

3. RESULTS

3.1 WOMBAT

The WOMBAT data were analyzed over the two-day sleep deprivation period, in order to elucidate any differential effects of drug preparation over time. All four subtasks were analyzed together in a 4 (drug group, between subjects) x 6 (session, within-subjects) mixed-model Multivariate Analysis of Variance (MANOVA). Scores were adjusted using an average baseline score collected at the beginning of the study period; each score was scaled using that subject's own baseline average on that variable before being entered into the analysis.

There were no significant main effects for drug condition, nor were there significant session main effects--which would signal differences based on the passage of time--for any of the subtasks examined here. There were drug by session interactions for the digit cancellation ($F(15,105) = 3.120$, $p<0.001$) and tracking ($F(15,105) = 2.717$, $p<0.001$) subtasks. Post hoc analyses revealed differences among drug groups on the digit cancellation task, but only during session five ($p<0.05$), at which point scores in the dextroamphetamine group were slightly, but significantly, lower than the caffeine group. There were no other pairwise differences demonstrated for the digit cancellation task. For the tracking subtask, scores differed between drug conditions during test sessions one, three and six ($p<0.05$). During session one, the dextroamphetamine group's scores were lower than the other groups' scores. During session three, the dextroamphetamine and the placebo group each scored lower than the modafinil group, but did not differ from one another. At session six, scores in the modafinil group significantly exceeded scores in the dextroamphetamine group (see Figure 1).

3.2. Flight Performance

The flight data consisted of seven standard maneuvers: hover, straight and level VMC flight, constant radius turn VMC, climb, constant radius turn IMC, straight and level flight IMC, and an ILS approach. Each score was a composite taken from the various components required to perform the maneuver. The magnitude of the score (out of max 100) represented the degree to which the subject maintained the proffered standard. Subjects' change from baseline performance was used to adjust for any naturally occurring differences due to ability or experience. These maneuvers were entered as variates in another 4 (drug group, between) x 6 (session, within) MANOVA.

These data yielded a significant main effect of drug condition for the hover ($F(3, 28) = 4.476$, $p<0.011$), and the climb ($F(3, 28) = 3.977$, $p<0.018$). Follow up comparisons revealed the pertinent pairwise difference on the hover was located in the modafinil group's superior performance as compared to the Dexedrine group. During the climbing maneuver, the effect was due to better performance by the Dexedrine group than the placebo group ($p<0.05$; Figure 2). No session main effects, nor drug by session interactions reached significance for any flight maneuver. Due to this unexpected dearth of drug and session related variance in the flight simulator performance, no regression comparison was performed between WOMBAT and flight performance.

4. DISCUSSION

The relative lack of drug and time-related effects on flight performance is surprising. Only two of eight maneuvers demonstrated any effect, and those two effects did not point to a consistent effect of drug condition or testing time. It seems possible that the new element of crew interaction during the simulated flight profiles may have injected an element of stimulation and excitement which was missing in previous single-subject/pilot research flights (Caldwell et al, 1994). Having another aviator in the next seat, who performed the duties of copilot, colleague, alertness monitor, etc., almost surely affected inflight performance. On the one hand, this makes it difficult to assess the 'worst case' fatigue scenario and the response to pharmacological countermeasures; on the other hand, aircrew operate as teams in the 'real world,' making this study more representative of the milieu in which fatigue countermeasures may be needed. In this study, no statistically significant effects of fatigue were shown over time in the simulator, even in the placebo group. This would compromise the study's ability to assess the benefit of pharmacological countermeasures, at least in comparison to previous studies.

On the other hand, the DUO WOMBAT task proved somewhat more sensitive to the counter-fatigue effects of these three stimulants. For three of the four WOMBAT subtasks (tracking, 3-D figure rotation and digit cancellation), the data clearly indicate a significant

interactive effect of fatigue and drug condition, where stimulant intervention sustained performance at acceptable levels relative to placebo, over time. However, there were no clear, consistent differences among the three drug groups (dextroamphetamine, modafinil and caffeine) in their ability to sustain performance over the deprivation period. The quadrant location task, which requires the participant to learn and remember numerical patterns, proved insensitive to the current manipulations, in that it produced no significant differences among groups based on time passage or drug condition. However, all three drugs maintained decision making, judgment and situational awareness, relative to placebo. Also, those capabilities, along with crew resource management, were sustained just as well in two-man crews as previously demonstrated in studies of individual aircrew performance. These findings strongly suggest that stimulant medications can assist the warfighter in maintaining acceptable levels of judgment and decision making, as well as crew coordination, when combat requirements dictate long periods of sleep deprivation. Future research will examine the resilience and vulnerability of team behavior as a fatigue countermeasure.

DISCLAIMER

The opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the U.S. Army and/or the Department of Defense.

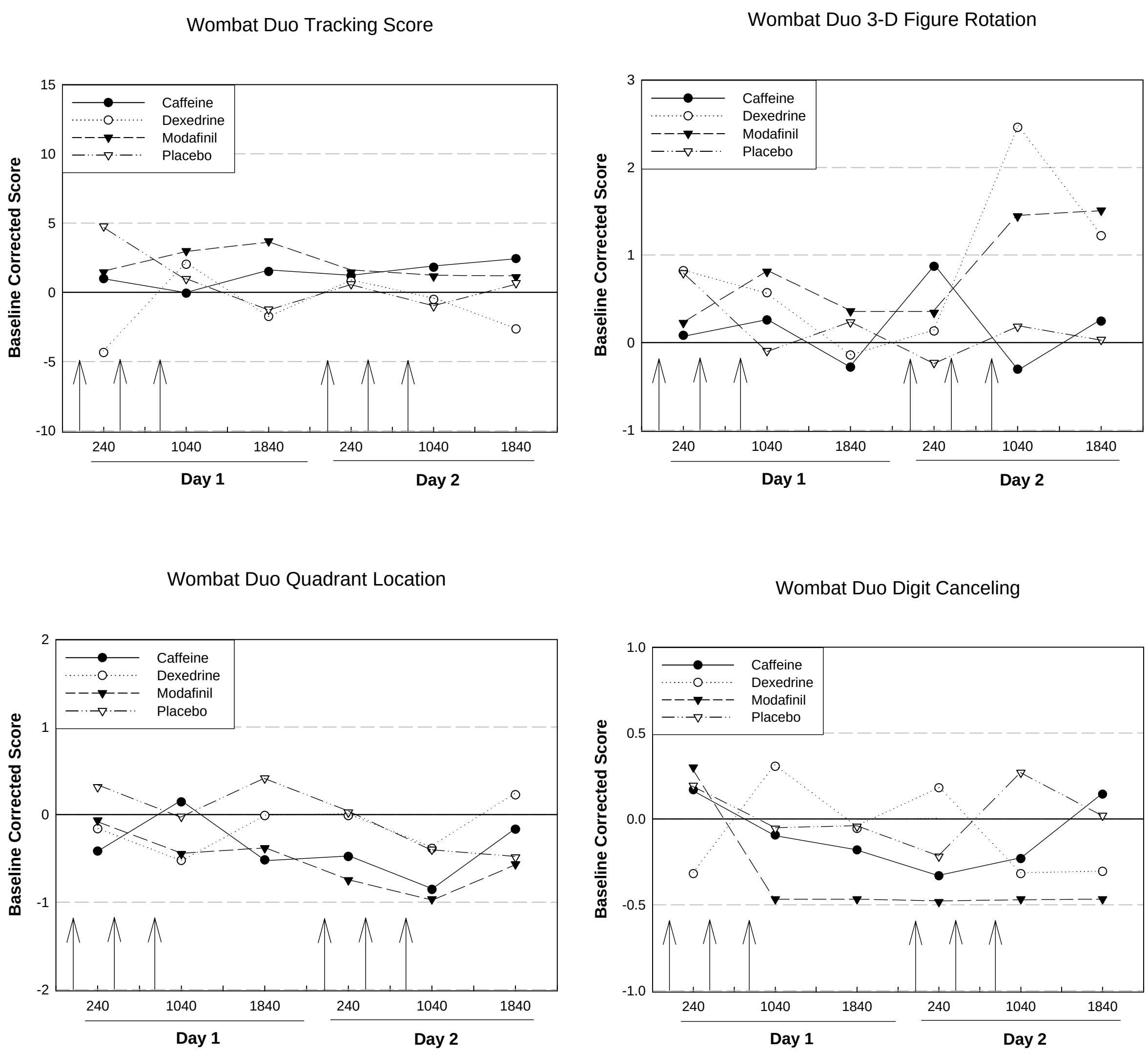

Figure 1. Performance trends on WOMBAT task.

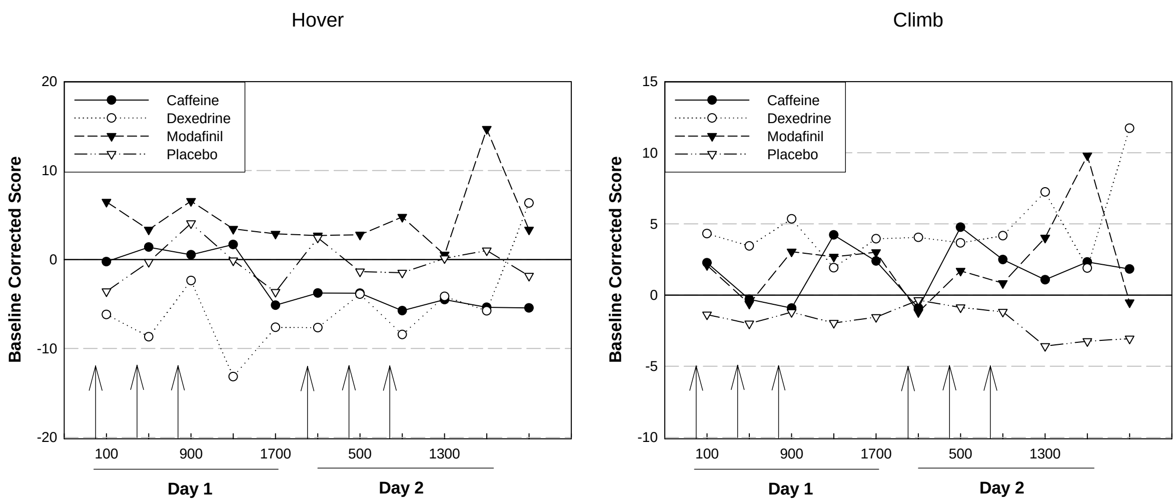

Figure 2. Selected aspects of flight performance trends.

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